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MONITORING OF ENVIRONMENT IN A FLASHOVER CONTAINER IN THE COURSE OF ENCLOSURE FIRE SIMULATION

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Research article

Abstract: This article presents the results of experimental determination of temperature field and heat flux density in a flashover container used for the training of firefighters. Experimental measurements were carried out in a chamber No. 1 of a firefighting trainer of Fire and Rescue Service of the Czech Republic at Zbiroh. The article describes the design and equipment of this chamber, used method of measurement and test procedure. Measured values of temperature field and heat flux density are stated and discussed. In conclusion, recommendations for further measurements in this chamber aimed at acquiring other findings concerning thermal loads on firefighters in the course of training are presented.

Key words: Flashover container, experiment, heat flux density, temperature.

Introduction

According to data published by the General Directorate of Fire and Rescue Service of the Czech Republic (Ministry of the Interior, 2012), in the period 2001 - 2011 more than 20 000 fires annually occurred on an average in the Czech Republic; the minimum number of fires was 15 966 in the year 2001 and the maximum number was 26 648 in the year 2003. Enclosure fires represent only a rather small part of the total number of fires. In the year 2011, fires in buildings and structures except for agricultural structures formed 22.6 % of the number of fires in which 74 people died, which corresponded to 57.4 % of all fire deaths. In this year, 734 people were injured, which corresponded to 63.7 % of all the injured.

Firefighter interventions in enclosed spaces belong to the most complicated and dangerous ones. During them, firefighters are very often exposed to extreme conditions represented by high temperatures and high density of heat flux, possible occurrence of dangerous substances in the air and decreased orientation ability induced by a content of solid particles in smoke, unknown geometry of space and unknown layout of furnishings. This all makes the rescue of persons and property inside buildings and the successful suppression of fires much more difficult.

For the quick and safe suppression of fires not only in enclosures, it is necessary to prepare firefighters systematically (Polakovič and Wawrzynkiewicz, 2009). A suitable way is practical training in conditions simulating real conditions of enclosure fires (Murphy and Molle, 2005). For this purpose, so-called flashover containers (henceforth referred to as FOC) began to be used also in the Czech Republic several years ago. In the containers the real conditions of enclosure fires can be simulated. Firefighters can be safely exposed here to the real conditions of enclosure fires and related phenomena. Simultaneously, FOCs make it possible to observe the course of the fire and demonstration of and training in various ways of water application to the space during fire extinguishing. At present, two facilities that use liquid propane as a fuel are operated in the area of the Czech Republic (School and Training Facility in Brno and Training Facility at Zbiroh), and another FOC situated in the municipality of Hamry (Fire and Rescue Service of Olomouc Region) that uses a solid fuel. The use of propane makes it possible to carry out, in a very short time period, repeated simulations of required conditions occurring in the course of the enclosure fire; another advantage of it is relatively clean operation without solid waste production.

The training facilities are to improve the professional training of fire brigades and to create conditions for safe service in accordance with Sections 70 and 72 of Act No. 133/1985 Coll., on fire protection (Act, 1985), Section 77 of Act No. 361/2003 Coll., on civil service of members of security forces (Act, 2003) and their implementing regulations.

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The aim of the work was to acquire values of selected physical quantities characterising an environment inside the FOC, specifically in a chamber No. 1 of a firefighting trainer at Zbiroh. Acquired values are used especially as data for the design of training methods in the FOC respecting the safety of intervening firefighters and for the operation of the facility at acceptable costs.

Description of the Firefighting Trainer at Zbiroh

The training facility is situated in the outskirts of the municipality of Zbiroh, on the premises of the 3rd Rescue Company of Fire and Rescue Service of the Czech Republic. The facility consists of several workplaces of different types intended for the training of brigades of Fire and Rescue Service of the region, where conditions during the fire in the enclosed and the outdoor space can be simulated. An FOC model for training in fighting the enclosure fire is shown in Fig. 1.

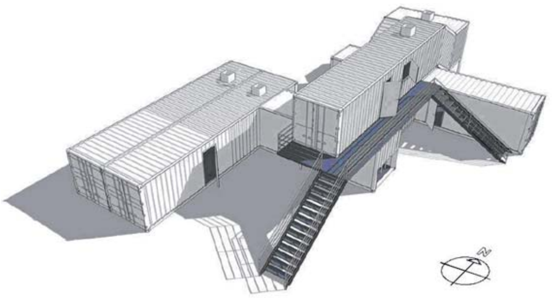

Fig. 1 Firefighting trainer model (Tomášek, 2010)

The base of the firefighting trainer (ground floor) is composed of containers Nos. 1 to 4. The first floor consists of a container No. 5, which is mounted on supports and welded on along the north side. The lateral walls of the containers Nos. 1 and 2 are cut to form a space (room) of rather large dimensions, a so-called "chamber" No. 1. The container No. 3 is divided into two parts connected with each other at a right angle. The structure of all containers is self-supporting.

In the vicinity of burners, the containers are protected by 50 mm thick thermal insulation Sibral covered with 1 mm thick steel sheets. Between the props of the light-gauge structure, 40 x 3 mm horizontal steel strips preventing the thermal insulation from settling are welded on to the container each 500 mm.

In all containers, concrete paving, 300 x 300 x 33 mm in size, laid on a 20 mm thick sand bed, is there. In the walls and the roofs of the containers, holes for window and door frames and vent stacks are created. Door and window wings are fabricated from steel sections, the infill consists of steel sheets 1.8 mm thick (Tomášek, 2010). Lever locks are mounted on them. On vent holes, position-adjustable sheets to control the supply of air to the burners are mounted. Vent stacks are fabricated from steel L-sections and are steel jacketed. The stacks are opened by means of a 5 mm diameter steel rope that runs from a stack cap lever through a pulley to an operating lever on the container wall. Operating levers are there on the internal as well as external side of the container. Each lever is equipped with a lock for keeping it in the open position. Stacks above the containers Nos. 1 and. 2 are interconnected with steel ropes so that they can be opened by one lever. Technical specifications are taken from (Tomášek, 2010).

Materials and methods

The experimental measurements were taken in the chamber No. 1 of the firefighting trainer to simulate the conditions of an enclosure fire. The enclosure is a space consisting of two transport ISO 1AA type containers, the technical data of which are given in Tab. 1. The space is primarily designed for training in the effective supply of extinguishing agent in a form of so-called 3D water fog.

Tab. 1 Selected technical specification for chamber No. 1

Chamber No. 1 (containers No. 1 and 2)		
Chamber width	inner	4 700 mm
Chamber length	inner	11 985 mm
Chamber height	inner	2 280 mm
Limited maximum burner output		2 211 kW
Number of gas-phase burners	ignition	1 x 4 kW
	stabilization	1 x 63 kW
Number of main burner nozzles		41

For the creation of flames for firefighting drill and simulation of enclosure fire conditions, a main propane burner with maximum output of 2.211 MW is installed in the chamber No. 1.

Burner output is regulated by propane supply control using a ball-valve with servodrive. This is controlled by buttons placed on a board.

The fuel for the firefighting trainer is propane, the selected parameters of which are given in Tab. 2.

Tab. 2 Selected properties of fuel (propane) (Tomášek, 2010)

Parameter	Value
Calorific value	93.57 MJ.m^{-3}
Explosive limits	2.12 - 9.35 %
Gas overpressure - liquid phase	500 kPa
Gas overpressure - gas phase	200 kPa

The supply of the gas phase of propane is led from a fuel bunker to an ignition and a stabilization burner in the chamber No. 1. The ignition burner is ignited manually using a suitable initiation source. By the ignition burner, the stabilization burner, which is designed for continuous igniting a main burner, is ignited. Technical data are taken from (Larva, 2010).

To ensure the uniform flame along the full length, the main propane burner installed in the chamber No. 1 is filled with liquid propane from three points, and three nozzle types differing in input resistance are used in it.

Based on previous experience and experience acquired in full-scale fire experiments, a layout of sensors of temperature and heat flux density was proposed. The sensor layout is shown in Fig. 2 and 3.

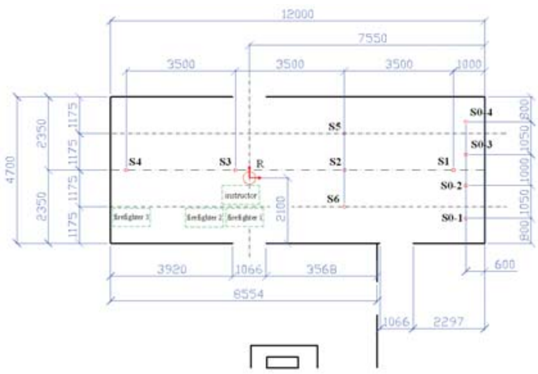

Fig. 2 Container ground plan showing the sensor layout

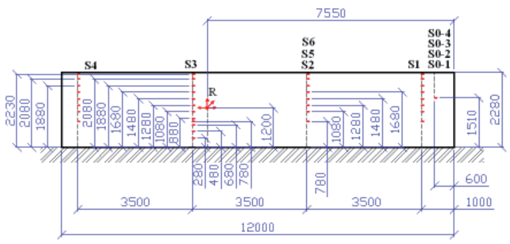

Fig. 3 Section through the container showing the sensor layout

For the measurement of temperature in the space, i.e. a quantity used for the description of natural and technical processes (Švec and Švec, 2008), heat-unshielded thermocouples were used. The utilization of them was similar to that in full-scale fire tests (ISO, 1996). Because in a case of heat-unshielded thermocouples, heat transfer by radiation between the flame and the thermocouple, and especially at high temperatures also between the thermocouple and cold walls takes place, the temperature measured by the thermocouple may differ from that of combustion products even by several ten of degrees Celsius (Zbieg and Grycmanová, 2009). Differences between the temperature of combustion products and the temperature measured by thermocouples in a compartment fire experiment are described also by (Mackay et al., 2010). For the purpose of measurement done, the temperature including also the radiation component is suitable and corresponds to the conditions to which firefighters and also objects inside the container will be exposed.

For sensing the temperature in the space altogether 34 NiCr/Ni jacketed thermocouples (K type) of diameters 1.0; 1.5 and 2.0 mm and further 22 thermocouples from K type thermocouple wire (HH-K-24-500) were used.

The thermocouples were placed in positions S0 to S6, see Fig. 2 and Fig. 3. The height placement of thermocouples in specific positions was designed with regard to acquiring values for the as accurate as possible determination of temperature field distribution. Installation was carried out on chains fastened to the ceiling of chamber No. 1 with a steel dead weight at the other end of each chain.

The thermocouples in positions S0-1 to S0-4 were connected to a data logger Almemo 2890-4S, the thermocouples placed in positions S1 - S6 to a data logger Almemo 5690-2M. Before starting the tests, correct positions and functions of particular thermocouples were checked. The data loggers were placed outside the container to ensure their easy and safe manipulation and protection against possible weather effects.

For measuring the density of heat flux, radiometers SCHMIDT-BOELTER SBG01 placed in the vicinity of a point of intervening firefighters near the position "instructor", see Fig. 2 and Fig. 3 (placement is designated as **R**) were used. The density of heat flux from various directions as stated in Tab. 3 was sensed.

The radiometers were mounted on a stand. As far as cooling the radiometers is concerned, the gravity flow of water from a tank situated on the first floor of the training facility was designed. The input signal wire, cooling water supply and drain hoses and radiometers with the exception of their frontal areas were protected by thermal insulation and reflective shield aluminium foil. Data from the radiometers were recorded using the data logger Almemo 5690-2M.

Tab. 3 Layout of radiometers during tests

Serial Number	Max. Value of Heat Flux [kW.m^{-2}]	Radiometer Orientation (in relation to container longitudinal axis)	Height [mm]
SN 1073 - 100	100	vertical (90°)	1200
SN 1061 - 50	50	horizontal (0°)	1040
SN 1062 - 50	50	incline (45°)	1190
SN 1340 - 10	10	rear (180°)	1150
SN 1341 - 10	10	left (0°)	1080

The experiment was divided into three tests according to the set operating output of the burner. The output corresponded to 30 percent, 60 percent and 90 percent of maximum output of the burner. Selected values of the operating output corresponded to those used in previous training in the FOC.

Each test consisted of 4 cycles; during each of them, the main burner was activated 5 times. The time of main burner activation was always 3 s, time between activation then 12 s (within this interval, a firefighting intervention is executed in the course of training itself). The time between cycles was 10 s (in training, participants change during this time). Burner activation in time is illustrated in Fig. 4.

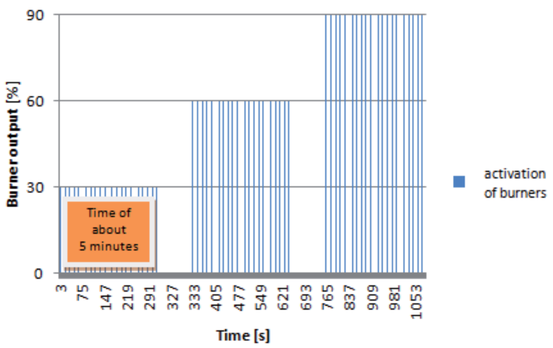

Fig. 4 Activation of gas burners in the course of tests

Before the measurement itself, one test cycle at output equal to 30 % of limited maximum output took place.

Positions of vent holes in the course of experiments are given in Tab. 4.

Tab. 4 Configuration of holes in chamber No. 1

Hole	Hole Configuration
Entrance gate - container 1	Open
Entrance gate - container 2	Open
Side door - container 1	Closed
Side door - container 2	Open
Side door - container 2 - passage into container 3a	Closed
Valve of vent stacks of containers 1 and 2	Closed
Hole for air suction below the burner	Open (270 mm hole height)

In the course of experiment, meteorological conditions were continuously measured and recorded at a distance of 20 m SE of the training chamber No. 1. A weather station Davis Vantage Pro2+ was used. Atmospheric temperature, humidity and pressure, wind direction and intensity, precipitation and solar radiation were observed.

Measured data processing was executed in programs MS Excel and Statgraphics Plus 5.0.

Results

Meteorological conditions in the time of experiment are presented in Tab. 5.

Tab. 5 Meteorological conditions in the time of experiment

Meteorological Conditions	
Atmospheric temperature	6.0 ± 0.1 °C
Atmospheric humidity	87 - 61 %
Average wind speed	0.2 m.s^{-1}
Primary wind direction	NNW
Squall (maximum)	2.7 m.s^{-1}
Atmospheric pressure	1022.9 hPa
Precipitation	0 mm
Solar radiation	0 W.m^{-2}

Fig. 5 illustrates the values of medians of temperatures measured in the burner flame at a height of 1510 mm from the floor. The position of thermocouples was chosen with regard to the direction of nozzles of the main burner and its position. The order of thermocouples on the graph corresponds to the placement in the container when viewed from the entrance gate of containers Nos. 1 and 2.

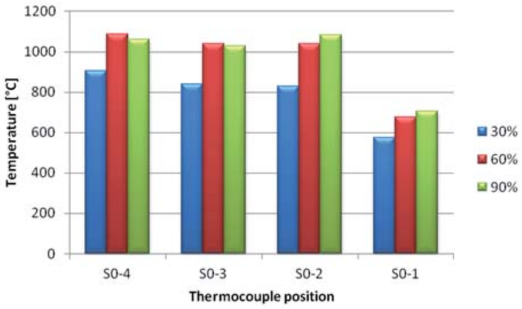

Fig. 5 Medians of temperatures at 1510 mm height in the place of burner at 30, 60 and 90 percent outputs

The evaluation of values of medians of temperatures in the space is carried out using images (see Fig. 6 and Fig. 7), in which filled contours of temperature field in a 2D section through a 3D space at outputs equal to 30 %, 60 % and 90 % of maximum output of the main burner can be seen.

In the interest of clarity, in the direction of axis x the graphs in Fig. 6 and Fig. 7 do not express the relative size of chamber No. 1in relation to the height placement of thermocouples, but they express merely a relative position towards each other.

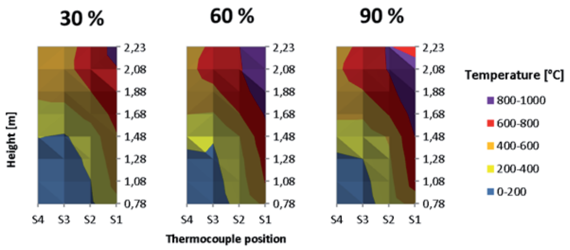

Fig. 6 Median of temperature field distribution in the container longitudinal axis at 30, 60 and 90 percent outputs

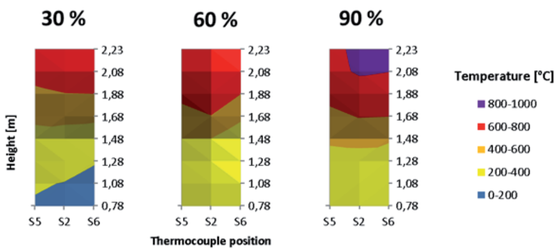

Fig. 7 Median of temperature field distribution in container cross section in the S5-S2-S6 axis at 30, 60 and 90 percent outputs

Medians of measured values of heat flux density from particular radiometers oriented in various directions in the plane of the container longitudinal axis and from a radiometer oriented left when viewed from the entrance gate of containers Nos. 1 and 2 are shown in the following graph in Fig. 8.

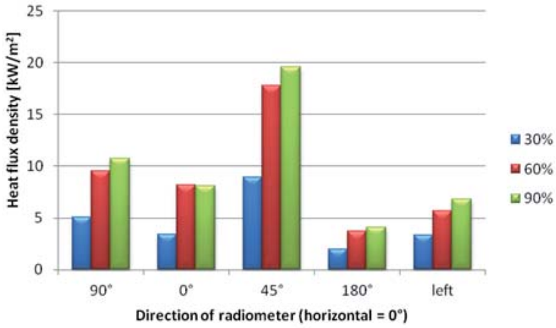

Fig. 8 Medians of heat flux density in container at 30, 60 and 90 percent outputs

Discussion

The pulsed mode of operation of the burner in the experiment (see Fig. 4) led to considerable fluctuations in measured temperature and heat flux density values. For this reason, medians as a measure of central tendency without the effect of extreme values were used for graph construction. Values in the graph in Fig. 5 show a markedly smaller difference between temperatures at 60 percent and 90 percent outputs of the burner than is a difference between temperatures at 30 percent and 60 percent outputs of the burner. This is probably caused by the insufficient supply of air for propane combustion directly in the area of the burner and by its gradual burning at a rather great distance from the burner. This is also confirmed by a detailed analysis of heat flux densities presented in Fig. 8. From the front direction in the horizontal plane (0°), what can be seen is a marked increase in heat flux density at 30 percent and 60 percent outputs of the burner; at

60 percent and 90 percent outputs any difference in heat flux density almost does not exist any longer. From the half-space in front of the radiometer inclined at an angle of 45°, above the radiometers (90°), from the left and from behind (180°), an increase in heat flux density confirming the given assumption can be seen at 60 percent and 90 percent outputs.

From the distribution of the temperature field illustrated in graphs in Fig. 6 and Fig. 7, a shift of rather high temperatures to larger distances from the burner is evident. The distribution of the temperature field in a longitudinal section through the chamber (Fig. 6) shows clearly the cooling of low-placed thermocouples in columns S4 and S3 due to the external air sucked through the open entrance gate as a result of natural exchange of gases in the chamber. The influence of the air sucked through the open right side door can be seen in the transverse distribution of the temperature field at the 30 percent output of the burner as illustrated in Fig. 7.

Conclusion

The measured values of the temperature field and the heat flux densities are basic input data needed for a proposal for safe training procedures for firefighters in FOCs. In the further phase, it will be necessary to focus on direct effects of high temperatures and heat flux densities on firefighters in the course of training in FOCs.

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